An Imitation of Life

Concerning the author's instructive genus of mechanical tortoises. Although they possess only two sensory organs and two electronic nerve cells, they exhibit "free will"

by W. Grey Walter

"When we were little . . . we went to school in the sea. The master was an old Turtle—we used to call him Tortoise."

"Why did you call him Tortoise if he wasn't one?" Alice asked.

"We called him Tortoise because he taught us," said the Mock Turtle angrily. "Really you are very dull!"

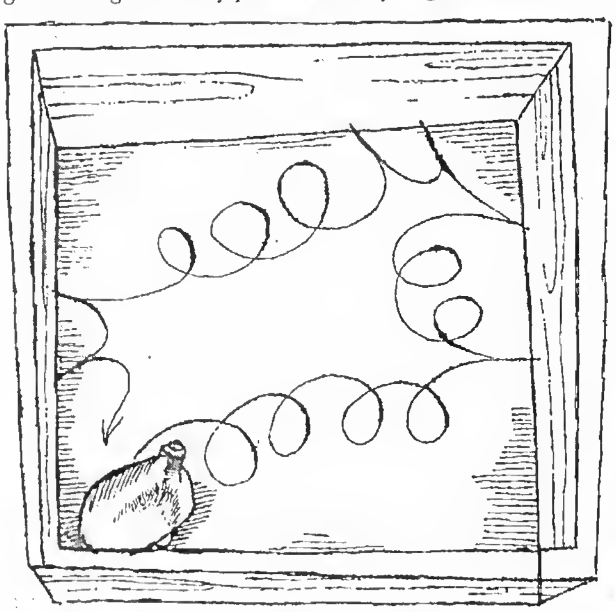
—Lewis Carroll, *Alice's Adventures in Wonderland*

IN THE DARK AGES before the invention of the electronic vacuum tube there were many legends of living statues and magic pictures. One of the commonest devices of sorcerers and witches was the model of an enemy which somehow embodied his soul, so that injury to the model would be reflected by suffering or death of the original. Even today it is not very uncommon to find in the cottages of European peasants wax statuettes of hated rivals stuck with pins and obscenely mutilated. One has only to recall the importance of graven images and holy pictures in many religions to realize how readily living and even divine properties are projected into inanimate objects by hopeful but bewildered men and women. Idolatry, witchcraft and other superstitions are so deeply rooted and widespread that it is possible even the most detached scientific activity may be psychologically equivalent to them; such activity may help to satisfy the desire for power, to assuage the fear of the unknown or to compensate for the flatness of everyday existence.

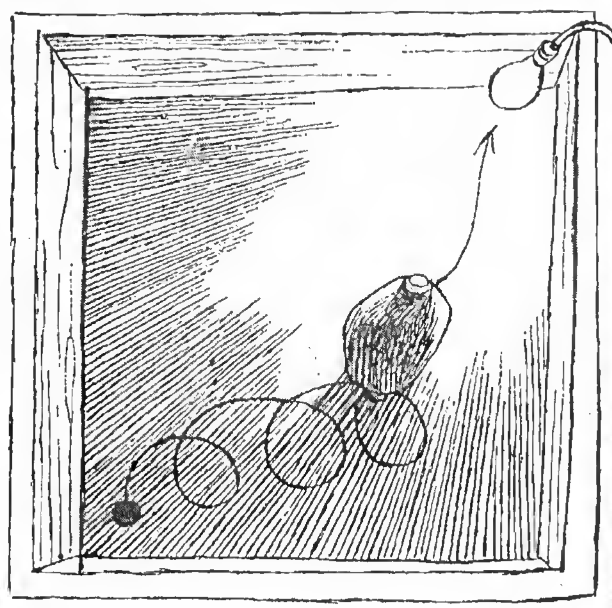
In any case there is an intense modern interest in machines that imitate life. The great difference between magic and the scientific imitation of life is that where the former is content to copy external appearance, the latter is concerned more with performance and behavior. Except in the comic strips the scientific robot does not look in the least like a living creature, though it may reproduce in great detail some of the complex functions which classical physiologists described as diagnostic of living processes. Some of the simpler of these functions can be duplicated by mechanical contrivances. But it was not until the electronic age that serious efforts were made to imitate and even to surpass the complex performance of the nervous system.

The fundamental unit of the nervous system is the nerve cell. In the human brain there are about 10,000 million such cells of various types, mostly concentrated in deep masses of "gray matter" or on the surface of the brain—the much-folded cerebral cortex. Between the cells run skeins of white matter, the interconnecting fibers. The unit of function is the nerve impulse, a miniature electrochemical explosion that travels along the outside of a nerve fiber as a vortex ring of negative ions.

All the gradations of feeling and action of which we are capable are provided by variations in the frequency of nerve impulses and by the number of nerve cells stimulated. The brain cipher is even simpler than Morse code: it uses



TORTOISE IN BOX describes a cycloidal path, backing up when it encounters a wall. In these drawings the tortoise features are somewhat exaggerated for clarity.



LIGHT IN BOX, picked up by the photoelectric "eye" of the tortoise, causes it to steer in that direction. When tortoise comes close to light, however, it backs away.

only dots, the number of which per second conveys all information. Communication engineers call this system "pulse-frequency modulation." It was "invented" by animals many millions of years ago, and it has advantages over other methods which are only just beginning to be applied. The engineers who have designed our great computing machines adopted this system without realizing that they were copying their own brains. (The popular term electronic brain is not so very fanciful.) In the language of these machines there are only two statements, "yes" and "no," and in their arithmetic only two numbers, 1 and 0. They surpass human capicity mainly in their great speed of action and in their ability to perform many interdependent computations at the same time, *e.g.*, to solve simultaneous differential equations with hundreds of variables.

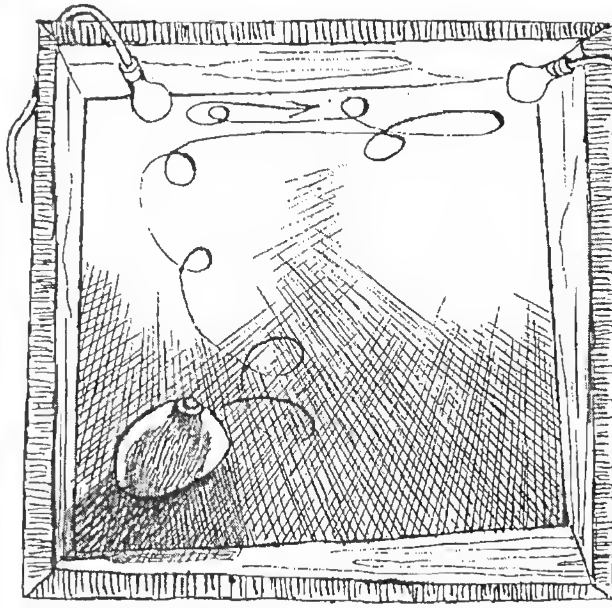
Magical though these machines may appear to the layman, their resemblance to living creatures is limited to certain details of their design. Above all they are in no sense free as most animals are free; rather they are parasites, depending upon their human hosts for nourishment and stimulation.

IN a different category from computing machines are certain devices that have been made to imitate more closely the simpler types of living creatures, including their limitations (which in a computer would be serious faults) as well as their virtues. These less ambitious but perhaps more attractive mechanical creatures have evolved along two main lines. First there are stationary ones—sessile, the biologist would call them—which are rooted in a source of electric power and have very limited freedom. The prototype of these is the "homeostat" made by W. R. Ashby of Gloucester, England. It was created to study the mechanism whereby an animal adapts its total system to preserve its internal stability in spite of violent external changes.

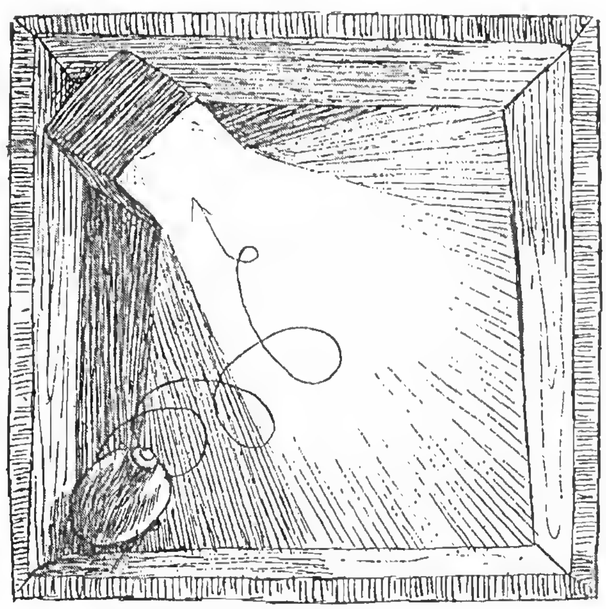
The term "homeostasis" was coined by the Harvard University physiologist Walter B. Cannon to describe the many delicate biological mechanisms which detect slight changes of temperature or chemical state within the body and compensate for them by producing equal and opposite changes. Communication engineers have rediscovered this important expedient in their grapplings with the problems of circuits and computers. They describe a system in which errors or variations from some desirable state are automatically neutralized as containing "negative or inverse feedback" ("Cybernetics," by Norbert Wiener; SCIENTIFIC AMERICAN, November, 1948). In their machines an error in performance or output is fed back into the input in such a sense that it opposes the signal responsible for the error. In an animal most of what is called reflex activity has exactly this property.

In Ashby's homeostat there are a number of electronic circuits similar to the reflex arcs in the spinal cord of an animal. These are so combined with a number of radio tubes and relays that out of many thousands of possible connections the machine will automatically find one that leads to a condition of dynamic internal stability. That is, after several trials and errors the instrument establishes connections which tend to neutralize any change that the experimenter tries to impose from outside. It is a curious fact that although the machine is man-made, the experimenter finds it impossible to tell at any moment exactly what the machine's circuit is without "killing" it and dissecting out the "nervous system"; that is, switching off the current and tracing out the wires to the relays. Nevertheless the homeostat does not behave very like an active animal—it is more like a sleeping creature which when disturbed stirs and finds a comfortable position.

ANOTHER branch of electromechanical evolution is represented by the little machines we have made in Bristol. We have given them the mock-biological name *Machina speculatrix*, because they illustrate particularly the exploratory, speculative behavior that is so characteristic of most animals. The machine on which we have chiefly concentrated is a small creature with a smooth shell and a protruding neck carrying a single eye which scans the surroundings for light stimuli; because of its general appearance we call the genus "Testudo," or tortoise. The Adam and Eve of this line are nicknamed Elmer and Elsie, after the initials of the terms describing them—ELectro MEchanical Robots, Light-Sensitive, with Internal and External stability. Instead of the 10,000 million cells of our brains, Elmer and Elsie contain but two functional elements: two miniature radio tubes, two sense organs, one for light and the other for touch, and two effectors or motors, one for crawling and the other for steering. Their power is supplied by a miniature hearing-aid B battery and a miniature six-volt storage battery, which provides both A and C



TWO LIGHTS IN BOX cause tortoise first to head for the nearest, then to back away from it and head for the other. Tortoise finally strolls between the two lights.



"KENNEL" IN BOX has light of certain brightness that attracts the tortoise only when its storage battery is run down. Battery is then recharged from contacts in kennel.

current for the tubes and the current for the motors.

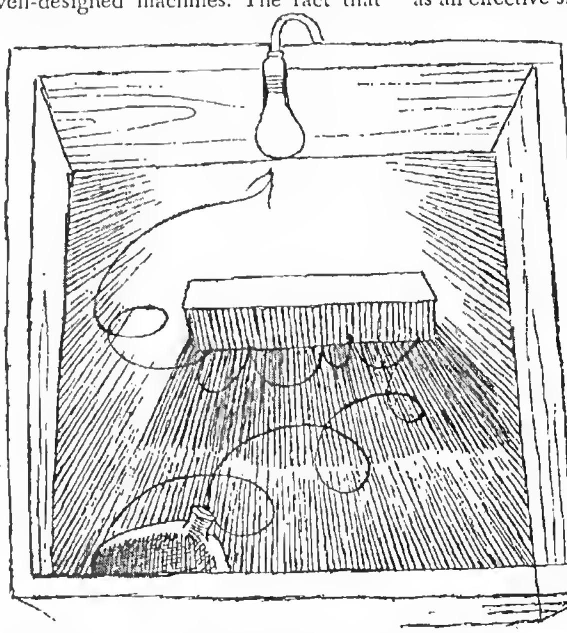
The number of components in the device was deliberately restricted to two in order to discover what degree of complexity of behavior and independence could be achieved with the smallest number of elements connected in a system providing the greatest number of possible interconnections. From the theoretical standpoint two elements equivalent to circuits in the nervous system can exist in six modes; if one is called A and the other B, we can distinguish A, B, A+B, A→B, B→A and A⇄B as possible dynamic forms. To indicate the variety of behavior possible for even so simple a system as this, one need only mention that six elements would be more than enough to form a system which would provide a new pattern every tenth of a second for 280 years—four times the human lifetime of 70 years! It is unlikely that the number of perceptible functional elements in the human brain is anything like the total number of nerve cells; it is more likely to be of the order of 1,000. But even if it were only 10, this number of elements could provide enough variety for a lifetime of experience for all the men who ever lived or will be born if mankind survives a thousand million years.

So a two-element synthetic animal is enough to start with. The strange richness provided by this particular sort of permutation introduces right away one of the aspects of animal behavior—and human psychology—which *M. speculatrix* is designed to illustrate: the uncertainty, randomness, free will or independence so strikingly absent in most well-designed machines. The fact that only a few richly interconnected elements can provide practically infinite modes of existence suggests that there is no logical or experimental necessity to invoke more than *number* to account for our subjective conviction of freedom of will and our objective awareness of personality in our fellow men.

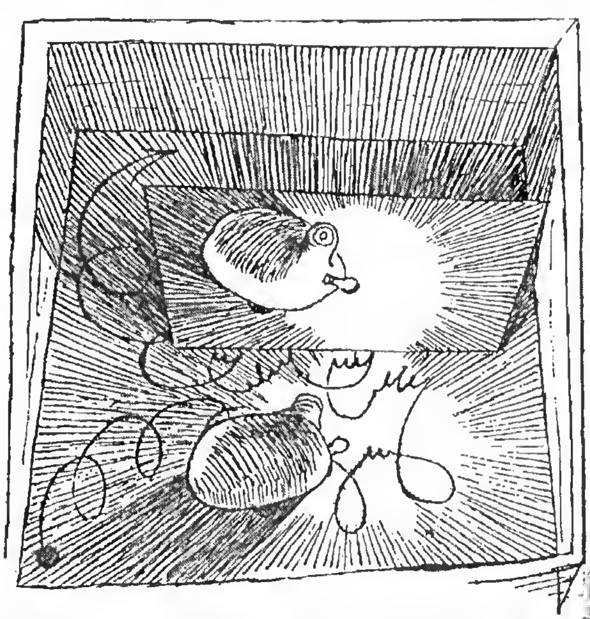
The behavior of Elmer and Elsie is in fact remarkably unpredictable. The photocell, or "eye," is linked with the steering mechanism. In the absence of an adequate light-stimulus Elmer (or Elsie) explores continuously, and at the same time the motor drives it forward in a crawling motion. The two motions combined give the creature a cycloidal gait, while the photocell "looks" in every direction in turn. This process of scanning and its synchronization with the steering device may be analogous to the mechanism whereby the electrical pulse of the brain known as the alpha rhythm sweeps over the visual brain areas and at the same time releases or blocks impulses destined for the muscles of the body. In both cases the function is primarily one of economy, just as in a television system the scanning of the image permits transmission of hundreds of thousands of point-details on one channel instead of on as many channels.

The effect of this arrangement on Elmer is that in the dark it explores in a very thorough manner a considerable area, remaining alert to the possibility of light and avoiding obstacles that it cannot surmount or push aside. When the photocell sees a light, the resultant signal is amplified by both tubes in the amplifier. If the light is very weak, only a *change* of illumination is transmitted as an effective signal. A slightly stronger signal is amplified without loss of its absolute level. In either case the effect is to halt the steering mechanism so that the machine moves toward the light source or maneuvers so that it can approach the light with the least difficulty. This behavior is of course analogous to the reflex behavior known as "positive tropism," such as is exhibited by a moth flying into a candle. But Elmer does not blunder into the light, for when the brilliance exceeds a certain value—that of a flashlight about six inches away—the signal becomes strong enough to operate a relay in the first tube, which has the reverse effect from the second one. Now the steering mechanism is turned on again at double speed, so the creature abruptly sheers away and seeks a more gentle climate. If there is a single light source, the machine circles around it in a complex path of advance and withdrawal; if there is another light farther away, the machine will visit first one and then the other and will continually stroll back and forth between the two. In this way it neatly solves the dilemma of Buridan's ass, which the scholastic philosophers said would die of starvation between two barrels of hay if it did not possess a transcendental free will.

For Elmer hay is represented, of course, by the electricity it needs to recharge its batteries. Within the hutch where it normally lives is a battery charger and a 20-watt lamp. When the creature's batteries are well charged, it is attracted to this light from afar, but at the threshold the brilliance is great enough to act as a repellent, so the model wanders off for further exploration. When the batteries start to run down, the first effect is to enhance the sensi-



LOW OBSTACLE prevents tortoise from heading straight toward light. Shell is mounted on a switch so that tortoise backs and "feels" its way around obstacle.



MIRROR causes tortoise with indicator light, again exaggerated for clarity, to flicker and jig. The light goes out when tortoise "sees" a light, even its own reflection.

tivity of the amplifier so that the attraction of the light is felt from even farther away. But soon the level of sensitivity falls and then, if the machine is fortunate and finds itself at the entrance to its kennel, it will be attracted right home, for the light no longer seems so dazzling. Once well in, it can make contact with the charger. The moment current flows in the circuit between the charger and the batteries the creature's own nervous system and motors are automatically disconnected; charging continues until the battery voltage has risen to its maximum. Then the internal circuits are automatically reconnected and the little creature, repelled now by the light which before the feast had been so irresistible, circles away for further adventures.

INEVITABLY in its peripatetic existence *M. speculatrix* encounters many obstacles. These it cannot "see," because it has no vestige of pattern vision, though it will avoid an obstacle that casts a shadow when it is approaching a light. The creature is equipped, however, with a device that enables it to get around obstacles. Its shell is suspended on a single rubber mounting and has sufficient flexibility to move and close a ring contact. This contact converts the two-stage amplifier into a multivibrator. The oscillations so generated rhythmically open and close the relays that control the full power to the motors for steering and crawling. At the same time the amplifier is prevented from transmitting the signals picked up by the photocell. Accordingly when the creature makes contact with an obstacle, whether in its speculative or tropistic mode, all stimuli are ignored and its gait is transformed into a succession of butts, withdrawals and sidesteps until the interference is either pushed aside or circumvented. The oscillations persist for about a second after the obstacle has been left behind; during this short memory of frustration Elmer darts off and gives the danger area a wide berth.

When the models were first made, a small light was connected in the steering-motor circuit to act as an indicator showing when the motor was turned off and on. It was soon found that this light endowed the machines with a new mode of behavior. When the photocell sees the indicator light in a mirror or reflected from a white surface, the model flickers and jigs at its reflection in a manner so specific that were it an animal a biologist would be justified in attributing to it a capacity for self-recognition. The reason for the flicker is that the vision of the light results in the indicator light being switched off, and darkness in turn switches it on again, so an oscillation of the light is set up.

Two creatures of this type meeting face to face are affected in a similar but again distinctive manner. Each, attracted by the light the other carries, extinguishes its own source of attraction, so the two systems become involved in a mutual oscillation, leading finally to a stately retreat. When the encounter is from the side or from behind, each regards the other merely as an obstacle; when both are attracted by the same light, their jostling as they approach the light eliminates the possibility of either reaching its goal. When one machine casually interferes with another while the latter is seriously seeking its charging light, a dog-in-the-manger situation develops which results in the more needy one expiring from exhaustion within sight of succor.

THESE machines are perhaps the simplest that can be said to resemble animals. Crude though they are, they give an eerie impression of purposefulness, independence and spontaneity. More complex models that we are now constructing have memory circuits in which associations are stored as electric oscillations, so the creatures can learn simple tricks, forget them slowly and relearn more quickly. This compact, plastic and easily accessible form of short-term memory may be very similar to the way in which the brain establishes the simpler and more evanescent conditioned reflexes.

One intriguing effect in these higher forms of synthetic life is that as soon as two receptors and a learning circuit are provided, the possibility of a conflict neurosis immediately appears. In difficult situations the creature sulks or becomes wildly agitated and can be cured only by rest or shock—the two favorite stratagems of the psychiatrist. It appears that it would even be technically feasible to build processes of self-repair and of reproduction into these machines.

Perhaps we flatter ourselves in thinking that man is the pinnacle of an estimable creation. Yet as our imitation of life becomes more faithful our veneration of its marvelous processes will not necessarily become less sincere.

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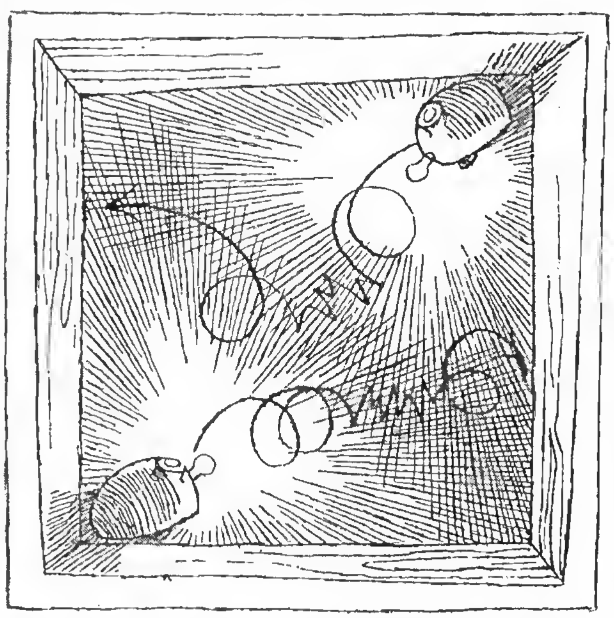
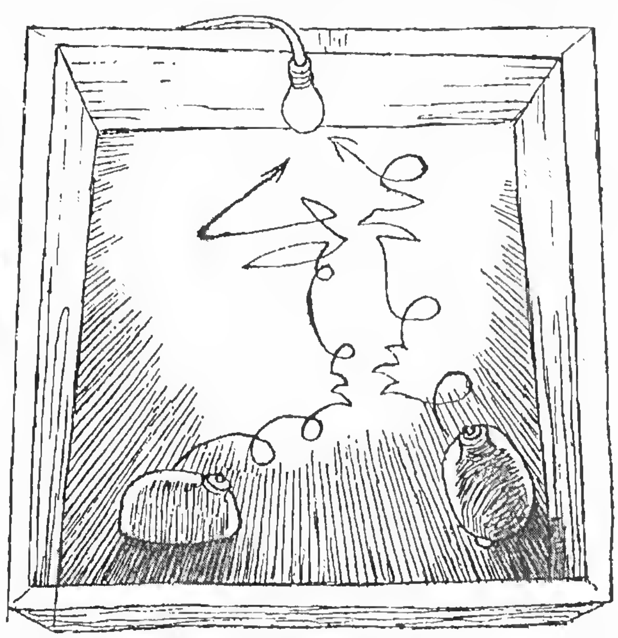


TWO TORTOISES WITH LIGHTS oscillate back and forth until they retreat from each other. The lights flicker as the steering motor of each is turned on and off.



TWO TORTOISES WITHOUT LIGHTS head toward a single light in a jostling manner. When their shells come in contact they briefly back away from each other.